

Study of the Six-seam Trawl-I

The Mechanical Characteristics of a Six-seam Trawl Net

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In order to improve the design of fishing gear and its performance, the knowledge of the characteristics of the gear in operation is of a major importance. Meanwhile, the behaviour of a trawl gear is much affected by its geometrical performance accompanied by hydrodynamic forces acting on. Considering that the hydrodynamic forces by the current on an operating trawl net finally act on the harness lines, and the geometric planform of the harness lines could be approximated to be a part of circular arc of various curvatures or a straight line, a set of twenty equations from the theoretical analysis of the geometrical configuration and the mechanical characteristics of a six-seam constructed trawl net is presented in this paper. To verify the validity of the theoretical analysis, a series of experiments on the six-seam trawl model was conducted in a ferro circulating water tank. Accordingly, the agreement between theoretical analysis and experiments of model was not close enough to be accepted uncritically, especially for its performance, however the analysis of the total resistances was in favorable agreement to the experimental results.

Introduction

Apparently the trawling gear developed from the original two-seam constructed trawl net to be four-seam, six-seam and eight-seam constructed trawl net, accompanied by the development in its methods and operations from one-boat small trawling to two-boat bigger trawling and from side trawler to stern trawler. The development in methods as well as in operations of trawling is due to rapid increase of oceanic fishing after the World War II. Nevertheless, much of those improvements was made by the employment of the gear based on trial-error methods.

Progress in scientific analysis and methods has made it feasible to construct and use mathematical models as well as mechanical models in analyzing the characteristics of the trawl net in operation, which are conceptually different from the models we are familiar with today.

Up to recent years, amongst many investigators who used the scientific analysis and methods in trawl gear research, KAWAKAMI¹⁾ reported the mechanical characteristics of drag-net, and obtained theoretically nineteen equilibrium equations of a dragnet configuration and its tension distribution. Then, NAKASAI et al.²⁾ studied the configuration of Danish seine, and obtained eighteen equations by means of the above-mentioned methods. On the basis of the research by KONDO and SUZUKI³⁾ on the

distribution of tensions on the Salmon drift-net that the force acting on any point of netting would be divided into two direction bars of mesh, KAWAKAMI and NAKASAI⁴⁾ restudied the mechanical characteristics of the drag-net and demonstrated theoretically new nineteen equilibrium equations of the gear.

Meanwhile, KOYAMA⁵⁾ observed the hydraulic resistance of six-seam trawl net used by six Japanese trawlers and then expressed an approximate resistance equation of the trawl net. With emphasis on designing of trawls, FRIEDMAN⁶⁾ used the calculation methods to analyze geometry and resistance of trawl based on general principle of mechanics and methods of similarity. And using the catenary formulae, DICKSON⁷⁾ established geometric planform of trawl net, and considering the required spread of the net by otter-board and the propulsion thrust of the towing vessels, he also obtained the total resistance of trawl gear.

Again, KAWAKAMI and NAKASAI⁸⁾ explained the theoretical derivation of characteristics curve of the four seam box-like trawl net by analyzing its mechanical situation and geometrical configuration in operation, and finally they obtained twenty equilibrium equations of trawl net. Applying the same methods of analysis by KAWAKAMI and NAKASAI⁸⁾, NAKASAI and FLORES⁹⁾ reported the mechanical characteristics of two-seam trawl net with thirty theoretical equilibrium equations. The comparative results of calculated values and observed values as have been demonstrated by KAWAKAMI and NAKASAI⁴⁾ as well as by NAKASAI and FLORES⁹⁾ show the applicability of theoretical treatment on the mechanical characteristics of both trawl nets. LEE¹⁰⁾ worked on the mechanical analysis of the beam trawl used in Taiwan, and he established fifteen equations with which satisfactory results were found from the comparison of analytical method with the results in the field experiment.

However, there has been carried out no study on the characteristics of six-seam constructed trawl net.

In Japan, there are various types of six-seam trawl, which are seemingly constructed according to the tonnage of trawler and the fishing ground¹¹⁾. Many fishermen, however, use the different types of six-seam trawl net in the same fishing ground for the same purpose with the same methods of operation, namely two-boat bottom trawl with stern trawler. It could be interpreted that this is due to inadequate information about the behaviour of the gear. Therefore, it is important to find and improve the standard gear. Before arriving in such a conclusion, the mechanical characteristics of the six-seam trawl net and its performance should be analyzed theoretically and observed experimentally.

In the line with theoretical studies on the mechanical characteristics of trawl nets by the above mentioned authors^{1,2,4,8,9)}, the theoretical analysis of a six-seam constructed trawl net based on general principle of its geometrical configuration and mechanical characters is presented in this paper with the hope to add the knowledge about trawl net.

Materials and Methods

Amongst various types of six-seam constructed trawl net, according to SASAKI¹¹⁾, Fishing Gear Research Laboratory of Nichimo Co. Ltd., the planform as shown in Fig. 1 (left) is a common gear used by Japanese two-boat trawlers. For the sake of simplicity to analyze its mechanical behaviour and its geometrical configuration in

general, the plan here is modified to a rather simple one as shown in Fig. 1 (right).

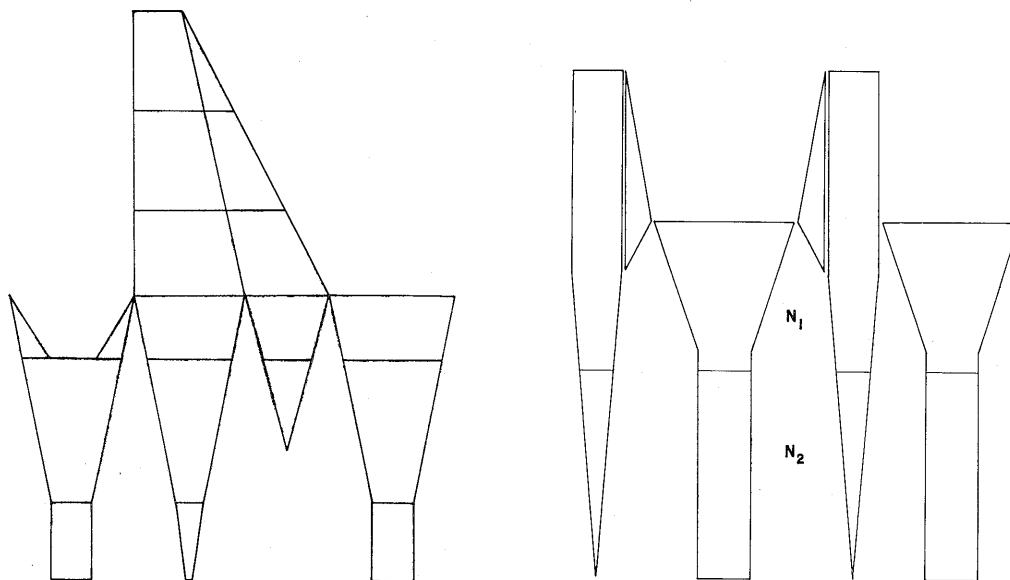


Fig. 1. Planform of practical six-seam trawl (left) and planform of experimental six-seam trawl (right).

Since the webbing materials used in the practical trawl net are partially different, the modified net treated here is also composed of two kinds of webbing : N_1 in the front part (wing, square, bottom and throat) of the net and N_2 in the rear part (cod-end).

Then, the analysis on the trawl is carried out by applying the same methods of analysis as have been demonstrated by KAWAKAMI and NAKASAI⁴⁾.

Finally, in order to verify the validity of the theoretical analysis, a series of experiments on the modified six-seam trawl model was conducted in a ferro circulating water tank.

Theoretical Analysis

Assuming the performance of the modified six-seam trawl in operation is such as shown in Fig. 2, since the hydrodynamic forces by the current on a trawl net finally act on the harness lines, the geometric planform of the harness lines could be best approximated to be a part of circular arc of various curvatures or a straight line if possible. So long as its geometrical and mechanical situations are evenly symmetrical about the centre line, we could treat the starboard side of the net and confine our consideration to the upper half of the net. The top and side view of this part accompanied by the mechanical equilibrium at the tip of wing are illustrated in Fig. 3. And the notations in this illustration are defined as follows :

| Notation | Description | Subscript | Meaning |
|----------|-----------------------|-----------|---|
| f | Force | w, szw | forward and rear parts of the wing respectively |
| T | Force per unit length | | |

| | | | |
|---------|-----------------------------------|-----|-----------------|
| K | Force per unit area | h | headline |
| L | Length of each section of the net | s | seamline |
| H | Depth of webbing | q | square |
| Y | Transversal distance | c | cod-end |
| Z | Vertical distance | o | tail of cod-end |
| R | Radius of curvature | e | elevation |
| β | Angle | n | normal |
| | | t | tangential |
| | | b | buoyancy |

Moreover, in order to obtain the equilibrium configuration of the net, its geometric planform, tension distribution and mechanical characters were simultaneously analyzed section by section, i. e. wing, headline and square, and the rear part of net as below:

Wing

The webbing of the side wing is seamed to the upper to the ribline and in the bottom to footline. Therefore, the tension of the upper half of the side wing is directed to ribline. Suppose that f_w is the force at the tip of the wing with angle of attack β_w as measured counterclockwise from the direction of normal

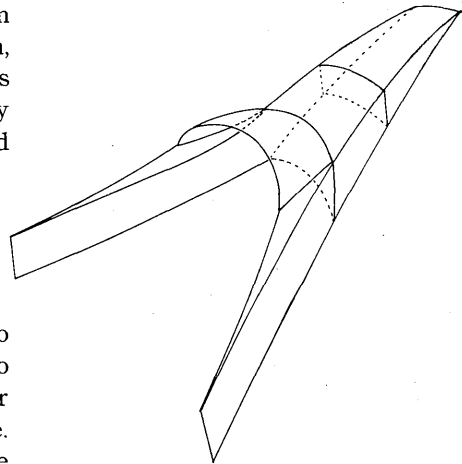


Fig. 2. Working performance of experimental six-seam trawl.

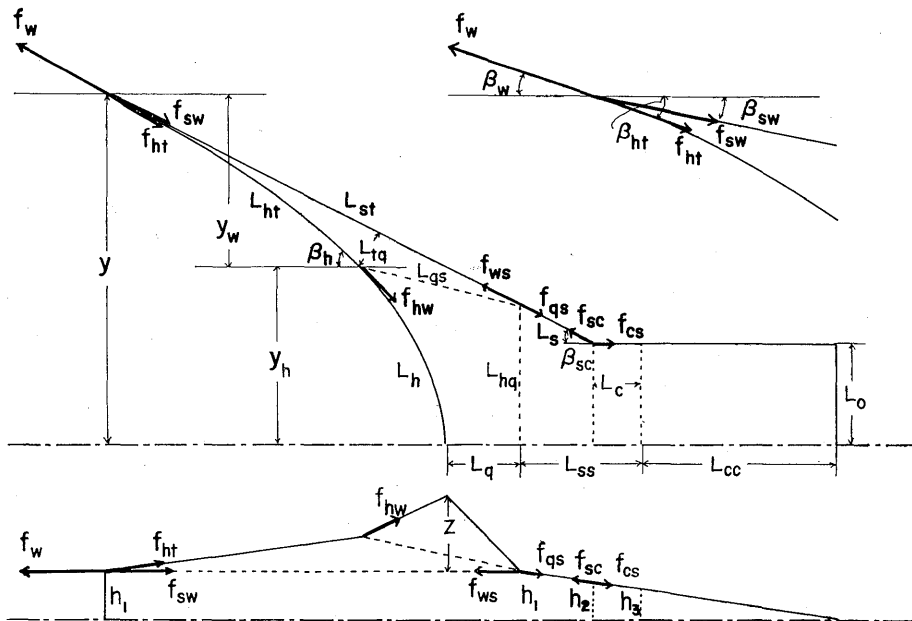


Fig. 3. Planform of harness lines of upper-half part of six-seam trawl. Showing side view (below), top view (middle) and forces working at the tip of wing (upper).

current, while f_{sw} is the ribline with angle β_{sw} . Since the force acting on any point of a webbing will be transmitted into two directions of bars mesh⁵⁾, the pattern of tension distribution of the upper part of webbing could be drawn as illustrated in Fig. 4,

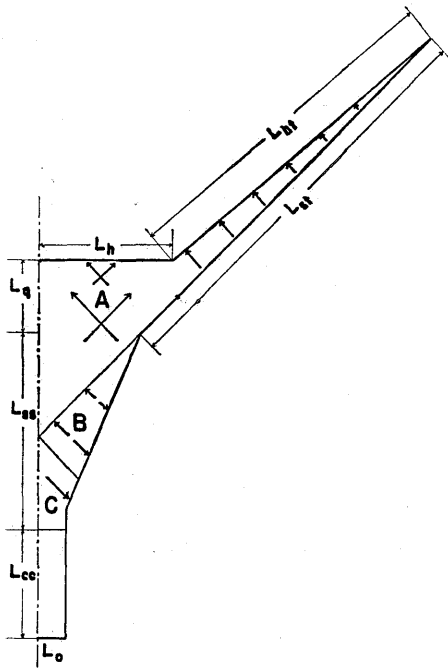


Fig. 4. Schematic representation of tension distribution of the upper-half part of net.

where the tensions of the triangle wing and the square are all imposed on the headline, and the tension of the throat half is imposed on the headline and the other half on the ribline. The remaining tensions affected by cod-end are all imposed on the ribline.

Supposing f_{ht} is the force in the front part (the wing section) of the headline contrary to the force in the forward (f_w) with its angle β_{ht} , as illustrated in Fig. 3, the equilibrium at the tip wing could be expressed:

$$f_w \sin \beta_w = f_{sw} \sin \beta_{sw} + f_{ht} \sin \beta_{ht} \quad (1)$$

and

$$f_w \cos \beta_w = f_{sw} \cos \beta_{sw} + f_{ht} \cos \beta_{ht} \cos \beta_e \quad (2)$$

where β_e is the elevation angle of the headline.

Next, let L_{st} be the length of forward ribline (along the longest edge of the triangle webbing) and L_{tq} be the normal distance from the tip of triangle perpendicular to the ribline L_{st} . If the angle of attack at the headline β_h with force on it f_h , we have:

$$f_{ht} (\beta_h - \beta_{ht}) = \frac{1}{2} L_{st} L_{tq} K_{n1} \sin \beta_h \quad (3)$$

where K_{n1} is the hydrodynamic forces by the normal current acting on a unit area of webbing N_1 .

Suppose f_{hw} is the force at the headline due to buoys, then we get:

$$f_{ht} - f_{hw} = -\frac{1}{2} L_{st} L_{tq} K_{t1} \cos \beta_h \quad (4)$$

where K_{t1} is the hydrodynamic forces acting on a unit area of the webbing N_1 when it is parallel to the current.

Let Y_w be the transversal distance of wings, then we get:

$$Y_w = L_{ht} (\cos \beta_{ht} - \cos \beta_h) / (\beta_h - \beta_{ht}) \quad (5)$$

Moreover, considering the rear part of wing or shoulder, suppose f_{ws} and f_{qs} respectively be the forces of the forward and rear directions (on the ribline) of this part, and the angle of attack of shoulder webbing at its depth h_1 be β_{sc} , hence the equilibrium equation in the rear part of wing may be expressed:

$$f_{sw} - f_{ws} = h_1 L_{st} K_{n1} \cos \beta_{sc} \quad (6)$$

And if T_{sw} be force per unit length of wing, while T_{ht} be the force per unit length of headline, then we have:

$$T_{sw} L_{ht} = -\frac{1}{2} h_1 L_{st} L_{tq} K_{t1} + T_{ht} L_{ht} \quad (7)$$

Let L_{ss} be the length of the projection of the throat to the centre line including L_{cc} which is the length from the end of shoulder to the front of cod-end, and if the length from the end of the longest side of triangle webbing to the end of shoulder

be L_s , then we find that:

$$f_{ws} = f_{qs} (L_{ss} - L_c) / L_s \quad (8)$$

Headline and square

The longest side of triangle webbing is seamed to the ribline L_{st} and the shortest side in the rear part to the side of square at length L_{qs} . Meanwhile the square hung to the headline at length L_h in the front, the headline in operation makes a curvature whose radius is R (Figs. 2 and 3).

Let L_{hq} be the length of the rear side of square, and L_q be the shortest distance between curved headline L_h to the rear side L_{hq} on the centre line. T_h being the resistance per unit length of headline including the float attached to it, and a being the angle between the shortest side of the triangle webbing L_{qs} and the headline L_h , the total force T_s that acts horizontally on the headline L_h may be expressed:

$$T_s L_h = \frac{1}{2} K_{t1} \left((L_h + L_{hq}) L_q + L_{hq}^2 \tan \varphi \right. \\ \left. \times \{1 + \sin(a - \varphi) \operatorname{cosec}(a + \varphi)\} \right) + T_h L_h \quad (9)$$

where φ is the angle between two adjacent bars which indicates the openness of a mesh.

Next, T_b being the average buoyancy per unit length of headline, the force acting on the headline with which its angle of elevation β_e faces the normal current may be expressed:

$$\frac{f_{hw}}{R} = \frac{T_b}{\sin \beta_e} \quad (10)$$

and

$$\frac{T_b}{T_s} = \tan \beta_h \quad (11)$$

For the relation between the length of curved headline L_h and the radius of the curvature, we have:

$$L_h = R \left(\frac{\pi}{2} - \beta_h \right) \quad (12)$$

and if Y_h be the transversal distance between the tip of headline L_h we get the equation:

$$Y_h = R \cos \beta_h \quad (13)$$

Finally, let Z be the height of headline for the angle of elevation due to the current, then we get:

$$Z = R (1 - \sin \beta_h) \sin \beta_e \quad (14)$$

Thus, we obtained all equations of the forward parts of the net.

Equilibrium at the rear part of net

Similar to the above ways, the equations of the rear part of the net could be composed. First let us consider the equilibrium equations on the seamline at the end of the shoulder webbing. Suppose the force f_e be the forward force with the angle of attack by the normal current β_{sc} (Fig. 3), then we have:

$$\beta_{sw} = \beta_{sc} \quad (15)$$

If L_o be the transversal width of the cod-end, then we obtain geometrically:

$$Y_h = L_s \sin \beta_{sc} + L_{qs} \cos a + L_o \quad (16)$$

Suppose the force by the normal current acting on the throat and cod-end be f_{sc} and f_{cs} respectively, then we get the equilibrium in the rear part as follows:

$$\begin{aligned} f_{qs} - f_{sc} = & \frac{1}{2} (h_1 + h_2) L_s \cos \beta_{sc} K_{n1} \\ & + \frac{1}{2} K_{t1} \frac{L_s}{L_{ss} - L_c} \left\{ L_{hq} \sin (a - \varphi) \operatorname{cosec} (a + \varphi) \right. \\ & \left. \times (L_s \sin a - L_{hq} \tan \varphi) \right\} + L_{hq} (L_s \sin a + L_{hq} \tan \varphi) \end{aligned} \quad (17)$$

and

$$\begin{aligned} f_{cs} = & \frac{1}{2} (h_2 + h_3) L_c K_{t1} + \frac{1}{2} h_3 L_{cc} K_{t2} \\ & + L_o \frac{L_s}{L_{ss} - L_c} (L_c K_{t1} + L_{cc} K_{t2}) \end{aligned} \quad (18)$$

also we have the relation between f_{sc} and f_{cs} as follows:

$$f_{cs} \cos \beta_{sc} = f_{sc} \quad (19)$$

The spread of wings

Finally in regard to the spread of wings Y or the transversal distance between the danlenos, we geometrically have the relation:

$$Y = Y_h + Y_w \quad (20)$$

Thus, after all, we have established a set of twenty equations of a six-seam trawl treated here, and before testifying its validity through a series of model experiments, we should calculate its quantity numerically with reference to the model net.

Numerical Computation

Before any quantitative analysis of the above established equations could be evaluated, it is necessary for more generality that all variables designating the force in the equation are divided by F ($=h_2 L_h K_{n1}$), those forces per unit length by T ($=L_h K_{n1}$), those representing forces per unit area by K ($=K_{n1}$) and those designating length by L ($=L_h$). Hence, a set of dimensionless equations corresponding to the theoretical equations are obtained.

Moreover, all twenty variables from the equations could be evaluated immediately, if the materials of nets (namely: the twine, mesh size, cork attached to headline, etc.), the towing speed and the dimensions of trawl net or some relation between those variables representing towing condition are given. After all, the equation could be completely solved numerically by applying the practical procedures which have been well demonstrated in the work of KAWAKAMI and NAKASAI⁴⁾.

Results of Computation

Similar to the literature²⁾, the important behaviour of a trawl net in operation could be best represented by the mutual relationship between the towing force acting on

the net and its working performance at different towing speed as indicating by the values of K or resistances of webbing. From the results of the above numerical computation, the mechanical characteristics curves of the six-seam trawl treated here could be drawn.

Accordingly, the relationship between the spread of wings (Y/L) and the angle of attack by the normal current on the tip of wing (β_w) is shown in Fig. 5. Clearly the

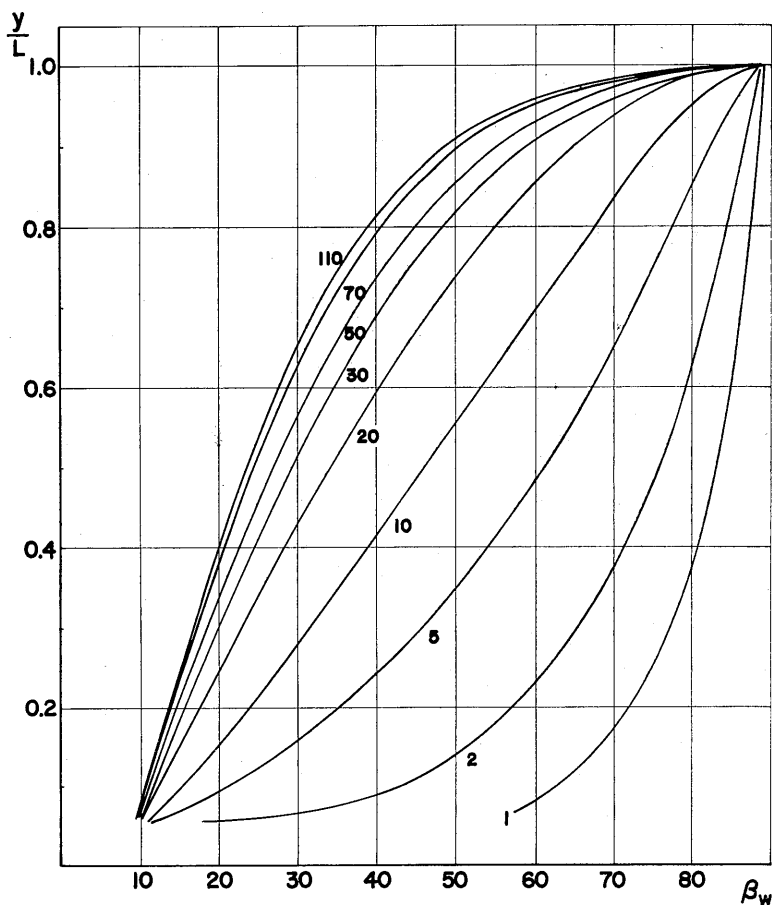


Fig. 5. Theoretical relation of the spread of wings (Y/L) to the angle of attack (β_w) at the tip of wing of six-seam trawl.

increase of towing speed - which is indicated here by the value of K from 1 to 110 - the spread of wings (Y/L : ordinates) will be wider, but the angle of attack (β_w : abscissa) will be smaller. However, at the same towing speed, wider spread of wings is followed by bigger angle of attack. This trend is true for each towing speed, but the increase of angle of attack is slow when the towing speed is low (when K is between 1 and 5) till the angle of attack $\beta_w = 70^\circ$, but it increases sharply after 70° . Conversely, the increase of the angle of attack exceeding 60° will be land slide, when the towing speed is higher (when the value of K is more than 20). From the point β_w exceeding 60° the spread of wings (Y/L) also becomes wider slowly.

Now, in regard to the relation between the elevation of headline (Z/L : ordinates) and the angle of attack (β_w : abscissa), as shown in Fig. 6, the increase in towing

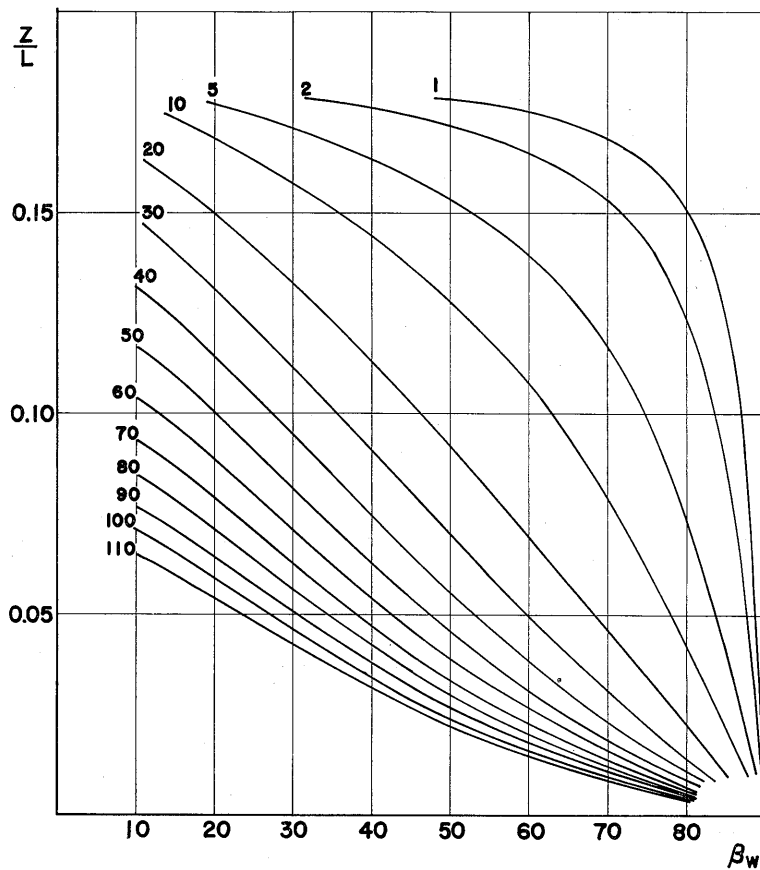


Fig. 6. Theoretical relation of the elevation of headline (Z/L) to the angle of attack (β_w) at the tip of wing of six-seam trawl.

speed (indicated by the value of K from 1 to 110) lowers the elevation of headline. Although this trend is true for every towing speed, there is a difference depending on the low-high towing speed. When the towing speed is lower (when the value of K is from 1 to 5), the decrease of the elevation of headline is slow till the angle of attack $\beta_w = 70^\circ$, but sharply decreases when β_w is more than 70° . On the contrary, if the towing speed is relatively high (K from 20 to 50) the elevation of headline decreases sharply. Then in higher towing speed, the decrease in the elevation of headline and the increase of the angle of attack β_w will be land slide.

Then on the relationship of the elevation of headline (Z/L : ordinates) to the spread of wings (Y/L : abscissa) as graphically shown in Fig. 7, the headline is obviously higher when the value of K is small or the towing speed is low, and the spread of wings is also narrow. In other words, the increase of towing speed causes the wider spread of wings followed by lower height of mouth net. And the mouth height decreases convergently following the increase in towing speed and the spread of wings (Fig. 7).

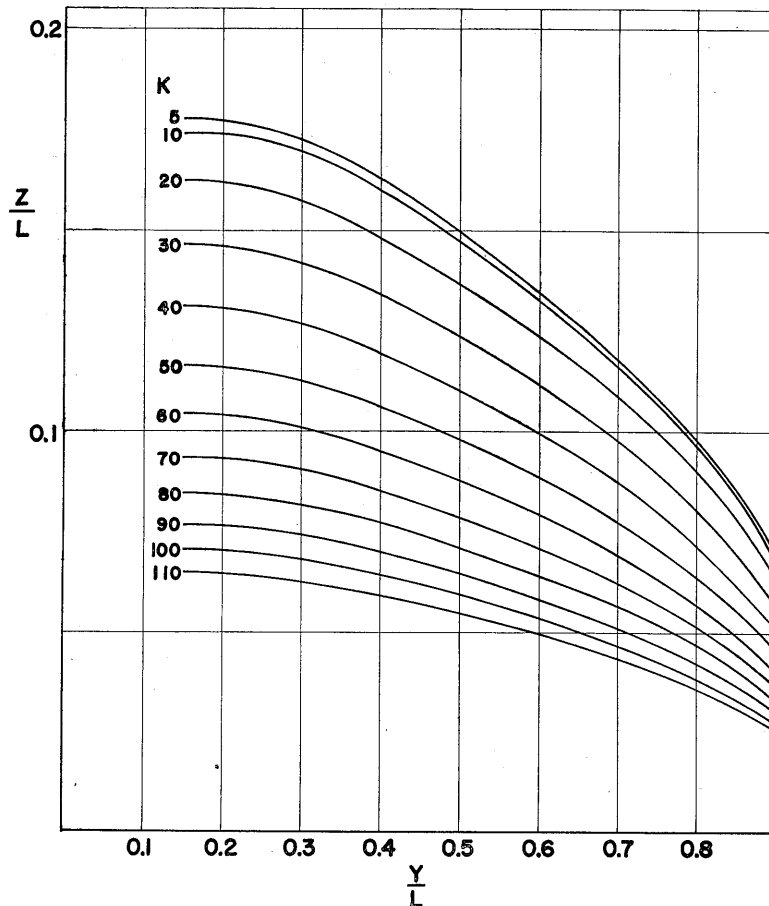


Fig. 7. Theoretical relation of the elevation of headline $\frac{Z}{L}$ to the spread of wings (Y/L) of six-seam trawl.

Furthermore, considering the relation between the total resistance of nets (f_w/f : ordinates) and the angle of attack (β_w : abscissa) as illustrated in Fig. 8, the total resistance of nets will be increased following the increase of the angle of attack, and especially when the angle of attack is more than 70° , it is evident that the total resistance of nets (f_w/f) increase sharply.

In addition, from the results of numerical computation, the relationship of the performance of net (represented by Y/L and Z/L) to the total resistance of nets (f_w/f) could also be drawn as graphically shown in Figs. 9 and 10.

Fig. 9 is in regard to the relation between the total resistance of nets (f_w/f : ordinates) and the spread of wings (Y/L : abscissa) for various towing speeds. It is plainly shown in this figure that if the spread of wings (Y/L) is wider, the total resistance of nets (f_w/f) will be greater, especially when the towing speed is relatively lower (when the value of K is less than 20). However, when the towing speed is higher or the value of K in reference to Fig. 9 is more than 50, no remarkable change of total resistance of nets could be found, even the spread of wings is increasing. In short, it could also be said that when the towing speed is higher, the increase in total resistance of nets will be less affected by the spread of wings.

In Fig. 10, the relationship of the total resistance of nets (f_w/f : ordinates) and the elevation of headline (Z/L : abscissa) is shown. In general, the value of Z/L (the elevation of headline or the height of headline) will be less followed by value of f_w/f (the total resistance of nets), when the value of K that indicates the towing speed is big. Though this tendency is true for each towing speed, however, the decrease of the total resistance of nets is sharp when the towing speed is relatively high (when the value of K is more than 20), accompanied by sharp decrease of the elevation of headline (indicated by Z/L values).

Experiment

Materials used for model experiment were a silk twine of diameter $D=0.03$ mm for all webbings, and the size of mesh $L_1=7$ mm for forward webbings N_1 (namely: wing, square, bottom and throat), while for the rear part of net webbing N_2 (cod-end) L_2 was 5 mm. The harness lines (namely: handline, headline, footline and ribline) were polyethylene couple twine of diameter $D=0.7$ mm.

The hang-in of webbing to the harness lines was made so as to make the openness of two adjacent bars of mesh an angle $2\varphi=90^\circ$.

The cork for buoy was plastic of diameter 7 mm making an average buoyancy in the headline $T_b=289.45$, while a tiny ferro-chain of length 50.4 cm was used for sinkers attached to footline.

Now, while referring to Fig. 3, the length of headline was also 50.4 cm, one half $L=25.2$ cm which was comprised of $L_{ht}=17.9$ cm and $L_h=7.3$ cm. The length of forward part of ribline or the longest side of triangle webbing $L_{st}=21.3$ cm and the rear part of ribline $L_s=9.4$ cm. The length of cod-end $L_{cc}=16.3$ cm and the width $2L_o=5.8$ cm. The height or depth of wing h_1 , of throat h_2 and the wall of cod-end h_3 were 3.08 cm, 2.14 cm and 1.95 cm respectively. Other dimensions of the model net used for quantitative analysis were as follows:

$$L_{iq}=2.34 \text{ cm}, L_{qs}=5.2 \text{ cm}, L_{hq}=5.9 \text{ cm}, L_q=4.9 \text{ cm},$$

$$L_{ww}=13 \text{ cm}, L_{ss}=8.8 \text{ cm}, L_c=2.4 \text{ cm},$$

$$T_h=0.0383 V^2, K_{t1}=0.026 V^2, K_{t2}=0.36 V^2, K_{n1}=0.052 V^2.$$

The techniques used for measurement of gear performance were the same as those well described in the reference⁹⁾; the only differences were in the recording of tension from the strain gauge which was amplified by an amplifier (DPM-IN W6170, Kyowa Electronic Instruments Co., Ltd.) and then finally connected to the linear recorder (Model WTR281, Watanabe Instruments Corp.) and in the bamboo beam (52 cm length) to adjust the spread of wings. The distance between two points

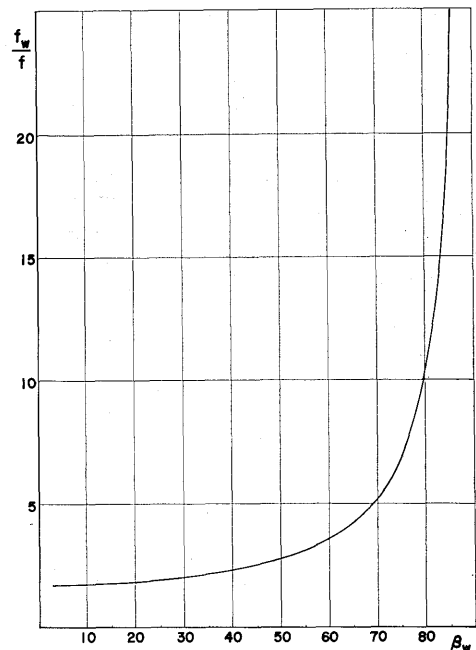


Fig. 8. Theoretical relation of the total resistance of nets (f_w/f) to the angle of attack (β_w) at the tip of wing of six-seam trawl.

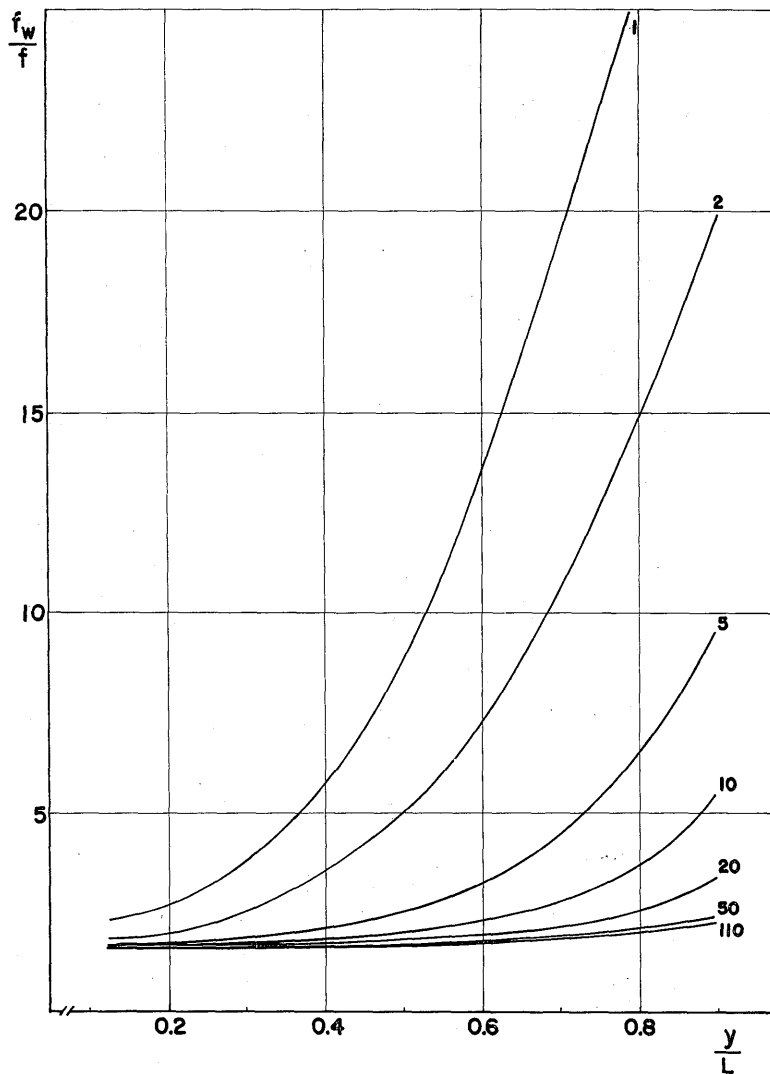


Fig. 9. Theoretical relation of the total resistance of nets (f_w/f) to the spread of wings (Y/L) of six-seam trawl.

ranging from 25 cm to 50 cm was divided at an interval of 5 cm for each water velocity ranging from 4.7 cm/sec to 46 cm/sec with an average interval 2.65 cm/sec. Hence, for each distance in the beam or for six steps of spread of wings, the tension and performance of nets were observed for 17 water velocities.

The condition of the ferro circulating water tank, where the experiment was conducted, has been well explained in the reference by FLORES and NAKASAI¹²⁾. During the experiment the water temperature was ranged from 25.1°C to 26.3°C and the room temperature from 28.1°C to 30°C, which were satisfactory for the conditions needed by the electronic instruments used.

As the examples of experiment conducted, a picture (left) taken from the top to record the spread of wings (Y) and the angle of attack β_w , and a picture (right)

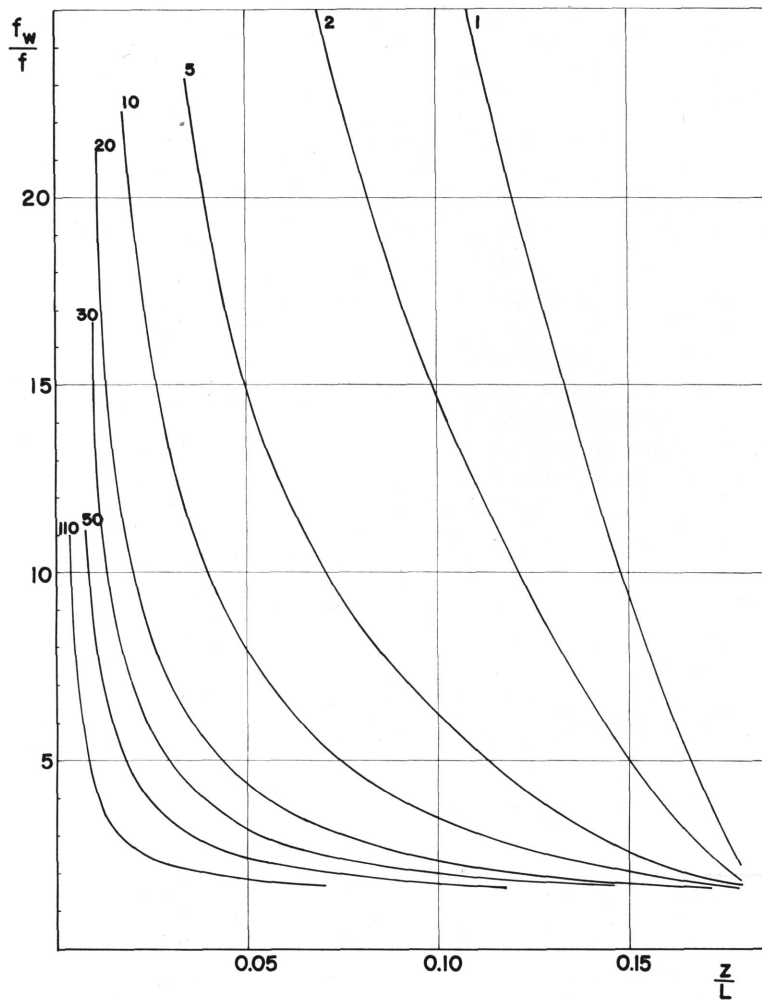


Fig. 10. Theoretical relation of the total resistance of nets (f_w/f) to the elevation of headline (Z/L) of six-seam trawl.

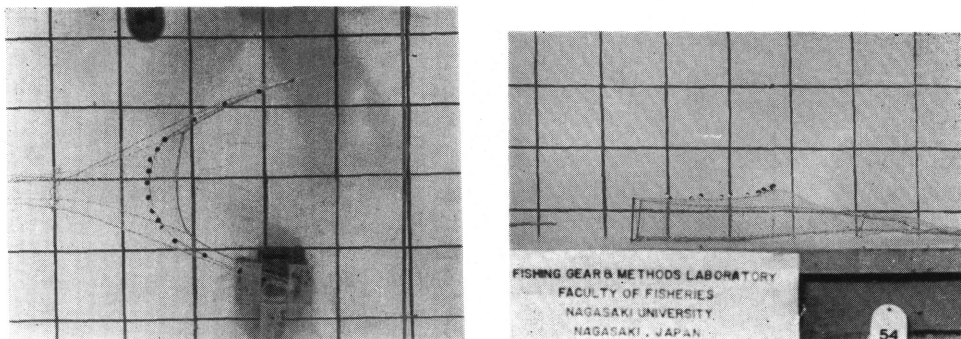


Fig. 11. Six-seam trawl model in the experimental water tank. Picture taken from top (left) and from side window of water tank (right).

taken simultaneously from the side window of water tank to record the height of mouth (Z) are presented in Fig. 11.

Results and Discussion

The observed value (Obs.) was obtained from the experimental results and the calculated value (Cal.) obtained from the numerical computation which was based on the theoretical analysis and the dimensions of model experiment was evaluated. Thus the both values were plotted for coincidence as a basis to verify the validity of theoretical analysis.

Here, though the range of the angle of attack at the tip of wing for the basis of numerical computation was between 5° and 85° at the interval of 5° , the angle of attack was only available between 10° and 37° in the experimental results, since the spread of wings was adjusted by the distance in the 52 cm length bamboo beam. Therefore, the comparison of both values were carried out within the experimental range of angle of attack.

The calculated value of the performance of net in operation is compared with the observed value in Figs. 12 and 13.

In Fig. 12, the calculated value (Cal : abscissa) of the spread of wings (Y/L) is

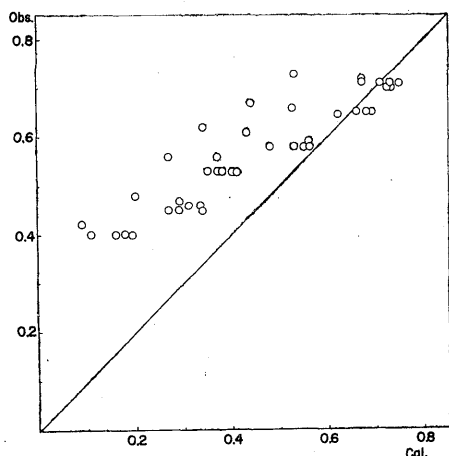


Fig. 12. Comparison between the calculated value (Cal.) and the observed value (Obs.) of the spread of wings (Y/L).

compared with the observed value (Obs : ordinates) within the experimental range of the angle of attack β_w . Since most of the marks are above the agreement line, clearly the observed value is slightly bigger than the calculated value, especially for low water velocity. However, when the water velocity is high, the relation between observed values and calculated values tends to be in agreement. Disagreement between both values is seemingly due to the methods of determination of the spread of wings (Y), especially in the experiment results. Similar to the report by NAKASAI and FLORES⁹⁾ on the theoretical studies of mechanical characteristics of two-seam trawl net, the wing under towing condition does not stand vertically to the bottom. It means that the spread of wings (Y) between the foot of danlenos differs from that of the head of danlenos.

During the experiment of the six-seam trawl model, the same cases obviously occurred almost on every occasion. Where, the spread of wings at the head of danlenos was a bit bigger than that of the foot of danlenos, as illustrated in Fig. 11 (left).

Theoretically the spread of wings of the calculated value was based on the assumption that the danlenos stand vertically to the bottom, while the observed value of the spread of the foot danlenos. Moreover, the measurement of the angle of attack was also improper, not only due to the difference between the spread of the foot and the head of danlenos, but also to the measurement method on the projection

of taken film (negative film), which should be improved. Therefore, a slight difference between the calculated values and observed values of the spread of wings is unavoidable, unless a new method of the measurement is developed. Moreover, of course it should be accompanied by the improvement in the theoretical analysis, and at least the spread of wings on both the head and foot of danlenos as well as the angle of attack at both points should be treated respectively. Therefore, as have been mentioned by CREWE¹³⁾, the formulae that are related to the angle of attack at the head and foot of danlenos should be developed for more accuracy of the spread of wings performance.

Nevertheless, since the spread of wings in the experiments was adjusted by the fixed distance at the bamboo beam, the spread of wings (Y/L) instead of β_w will be used as a basis of the comparison between the calculated value and the observed value of the height or the elevation of headline (Z/L) as well as the total resistance of nets (f_w/f) to avoid further insufficient agreement between the observed and calculated values.

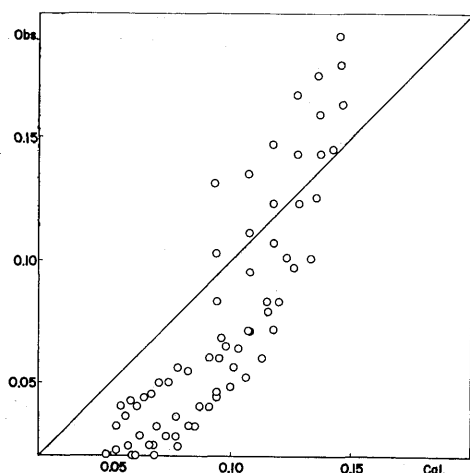


Fig. 13. Comparison between the calculated value (Cal.) and the observed value (Obs.) of the elevation of headline (Z/L).

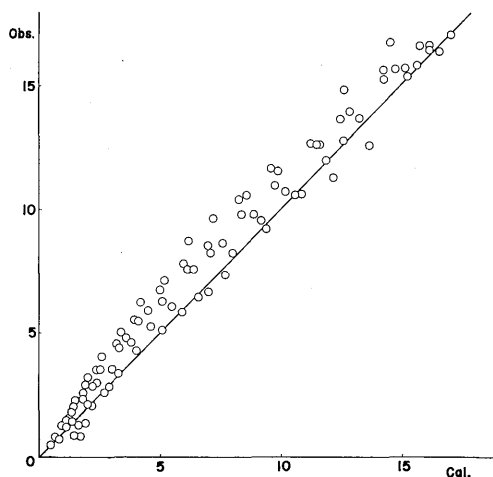


Fig. 14. Comparison between the calculated value (Cal.) and the observed value (Obs.) of the total resistance of nets (f_w/f), showing good coincidence of both values.

The comparison of the calculated value of the elevation of headline with the observed value, as plotted in Fig. 13, shows an agreement, especially when the water velocity is lower or when the value of K is less than 5. But, if the value of K is more than 5, the observed value will be bigger than the calculated value. As shown in Fig. 13, clearly the clusters of both values are scattered above and below the agreement line. The fact that more clusters are below the agreement line could be interpreted that the calculated value is a bit bigger than the observed value. The difference between both values apparently is due to the fact that the spread of the foot of danlenos vertical to the bottom as the basis of the calculated value was wider than the spread of the foot of danlenos as the basis of the observed values.

Moreover, contrary to the general tendency in comparison of both values of the headline, the calculated value of the total resistance of nets is in good agreement with the observed value, although a little bigger in the observed value, as plotted in

Fig. 14. It seems that the little difference is due to the hysteresis effect and the friction of pulley during the experiment.

As illustrated in Figs. 12, 13, 14, the calculated value and observed value of trawl performance were not in satisfactory agreement. While the calculated value was bigger for the elevation of headline, the observed value was bigger for spread of wings. Meanwhile, the calculated value of the total resistance of nets was almost in agreement with the observed value. Those phenomena might also be affected by the difference in method and instruments of measurement. The electronic instruments used in the experiment were obviously more efficient than the other instruments or recording instruments.

Conclusion

On the theoretical analysis of mechanical characteristics of a six-seam trawl treated here, a set of twenty equations of the six-seam trawl have been established theoretically, and the gear performance graphs presented in this paper (Figs. 5 to 10) show the characteristics curve of the six-seam trawl. These have been derived from numerical computation based on the theoretical equations and the dimensions of a model six-seam trawl.

From a series of model experiments conducted to verify the validity of theoretical analysis, it is generally found that on the comparisons of calculated values and observed values of trawl performance, the agreement between theoretical analysis and experimental results was not close enough to be accepted uncritically. And therefore, the theoretical analysis as well as the methods of measurements should be improved, and at least the formulae related to the angle of attack at the foot and the head of danlenos should be established. On the other hand, as the calculated values of the total resistance of nets were compared with the observed values, the both values were scattered adjacent to the agreement line or were almost in close agreement.

Therefore, in summary, good coincidence between calculated value and observed value, as mentioned above, may be used as a reasonable validity of theoretical analysis on the mechanical characteristics of the six-seam trawl. In other words, it could also be best stated that a set of twenty equations of a six-seam trawl established in this study is applicable to the consideration of or reference to the performance and characteristics curve of the six-seam trawl in practice.

References

- 1) KAWAKAMI, T.: On the mechanical characters of the drag net. *Mem. Coll. Agr. Kyoto Univ.*, 72, (Fish. Ser. No. 5), 1-4 (1955)
- 2) NAKASAI, K., O. SUZUKI and T. KAWAKAMI: Studies on the configuration of Danish seine *Bull. Jap. Soc. Sci. Fish.*, 27, (7), 641-644 (1961)
- 3) KONDO, Y. and M. SUZUKI : The measurement of tension on the salmont drift net-I. *Bull. Jap. Soc. Sci. Fish.*, 25, (5), 346 (1959)
- 4) KAWAKAMI, T. and K. NAKASAI : On the mechanical character of the drag net-II. *Bull. Jap. Soc. Sci. Fish.*, 29, (7), 644-670 (1962)

- 5) KOYAMA, T.: Resistance of trawlnet. *Bull. Jap. Soc. Sci. Fish.*, **23**, (2), 74-78 (1967)
- 6) FRIEDMAN, A. L.: "Geometry and resistance of trawls". FAO/USSR Seminar on Instrumentation and Methodology in Fishing Technology, FAO-UN, 35-71 (1967)
- 7) DICKSON, W.: Trawl gear geometry and resistance. FAO/USSR Seminar on Instrumentation and Methodology in Fishing Technology, FAO-UN, 73-94 (1967)
- 8) KAWAKAMI, T. and K. NAKASAI : Theoretical derivation of characteristics curve of trawl nets. *Mem. Coll. Agr. Kyoto Univ.*, **94**, (Fish. Ser. No. 9), 1-16 (1968)
- 9) NAKASAI, K. and E. FLORES : Theoretical studies on the mechanical characteristics of two-seam trawl net. *This Bull.*, **32**, 113-128 (1971)
- 10) LEE, T. J.: Mechanical studies on trawl gear of Taiwan. *Taiwan Fish. Res. Inst.*, 65-72 (1972)
- 11) SASAKI, H.: On two-boat trawl net. *jour. Fish. Boat. Ass. Jap.*, **172**, 35-40 (1971) (In Japanese)
- 12) FLORES, E. and K. NAKASAI: On the flow distribution of an experimental circulating water tank. *This Bull.*, **32**, 103-111 (1971)
- 13) CREWE, P. R.: Some of the general engineering principle of trawl gear design. "Modern Fishing Gear of the World-2", Fishing News (Books) Ltd., London, 165-181 (1964)